and the lower switching about in a cloud of dust on the ground, you can imagine something of what the twister looked like when it passed Hardtner."

When the tornado disappeared, ambulances were rushed to Hardtner from as far as Alva, Okla., almost 20 miles distant, under the supposition that the town had been wiped out and hundreds of persons mangled or killed. Fortunately only the edge of the town had been struck and no one was injured. People had seen the tornado approaching and had taken to storm caves—the well known "cyclone cellars" of the West—and basements, where they were safe. After the disturbance was over it was reported, "People came out of the ground like ants."

As in the case of many tornadoes, this one was accompanied by a heavy fall of hail. At Kiowa, 10 miles to the east, where the sun could still be seen shining over the top of the tornado cloud, slugs of ice, disk shaped, and 2½ inches wide and almost an inch thick, fell in the sunlight like gleaming meteors out of a black cloud that backed in from the east. Finally, the parent cloud of the tornado merged with the black hail cloud and the whole mass moved off toward the northeast.

551.515 (759)

PENSACOLA WATERSPOUT OF JUNE 14, 1929

By Lieut. P. G. HALE, U. S. Navy

A waterspout occurred in Pensacola Bay from 9:31 to 9:37 on the morning of the 14th of June, 1929. A somewhat detailed report of the occurrence is made, for it is believed that some new data will be made available for the study of waterspouts. The waterspout was not a large one and lasted only six minutes, but it is the attendant data which excuses the length of the report.

To begin with, an aerograph (airplane meteorograph) flight was made that morning up to 3,000 meters. The writer of this article was the observer. The following are the notes taken during the flight:

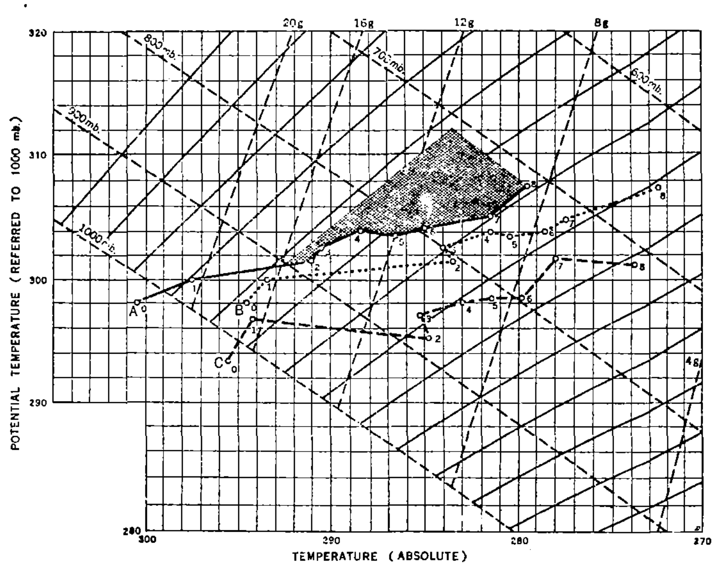

FIGURE 3.—Enlarged portion of tephigram of Figure 2. (See text.)

> Takeoff at 0624. Light haze. Tall cumulus over the Gulf of Mexico. Few strato-cumulus around the horizon. Base of the cumulus about 450 meters. Haze ring to the east at an altitude of about 2,800 meters, cumulus thrust through it in places. Tops of the cumulus over the Gulf of Mexico were well over 3,000 meters. Quite bumpy throughout the flight. Top of the flight at 0646.

After landing the data were worked up, using an adiabatic chart and a tephigram chart to plot them. The instrument used on the flight was a Friez aerograph, type Aero-1928-USN, No. 51. Frequent calibrations insure that the instrument is reasonably correct. A copy of the work sheet used in picking off the data from the aerograph chart accompanies this report.

On the adiabatic chart (fig. 2) there are plotted (1) a temperature-pressure curve; (2) a curve to determine graphically the altitude of the significant points; (3) a humidity-pressure curve; (4) a wind velocity curve, from pilot balloon ascent at 0600; (5) wind velocity-altitude curve, from pilot balloon ascent immediately following the waterspout, about 10 a. m.; and (6) a vapor pressure-pressure curve. These various curves are labeled on the adiabatic chart. The 6 a. m. pilot balloon ascent reached an altitude of only 1,530 meters, when the balloon was lost due to haziness. The ascent immediately following the waterspout was made to an altitude of 5,300 meters, where the balloon disappeared behind a cumulus cloud.

The aerograph sounding is plotted on a tephigram chart (fig. 3) the scale of which is rather small, so an enlarged portion of the tephigram chart is magnified and the sounding replotted on it to better show the details. Both the tephigram chart and the magnified portion on a separate page are submitted with this report (fig. 3).

The upper left curve "A" is the tephigram or temperature-potential temperature curve on the tercentesimal scale. The lower right hand curve "C" is the dew-point temperature plotted against the pressure. The central curve "B" is a curve connecting the points at which air rising adiabatically from points on the tephigram, curve "A," would become saturated and begin to form cloud.

For a description and better understanding of the curves plotted see "Physics of the Air," by W. J. Humphreys, second edition, 1929, pages 259–261.

The shaded area represents the energy-per-unit mass of saturated air available for convection from lower to higher levels. The upper right edge is cut off at the end of the tephigram, as no information is available above point "8" and no assumptions are made. It might be noted that the entire area as shaded really is representative of the energy available at point "1." An area almost as large would represent the energy available at the surface or point "0." At point "2" there is no energy available and but a slight amount at point "3." Another feature of the tephigram, curve "A," is that except between points "2" and "3" and points "7" and "8" the curve is more nearly horizontal than the psuedo-adiabats, and thus air from the surface up to point "7" once saturated becomes unstable except for the shallow layer between "2" and "3."

Tephigrams are drawn daily as part of the routine at the United States naval air station, Pensacola, Fla., and they are completed prior to the completion of the weather map. So far, their principal use has been in the prediction of thunderstorms for the current day. This is based on a study of the size of the energy area and the levels at which energy is available. In general when curves "A" and "B" are widely separated and the energy does not exist thunderstorms do not occur. When the two curves are close together and the energy area is evident but not large, thunderstorms may or may not occur. When

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FIGURE 1.—Waterspout in Pensacola Bay, June 14, 1929, taken from an O-2V landplane. (Published by permission of the Chief, Bureau of Aeronautics, Navy Department)

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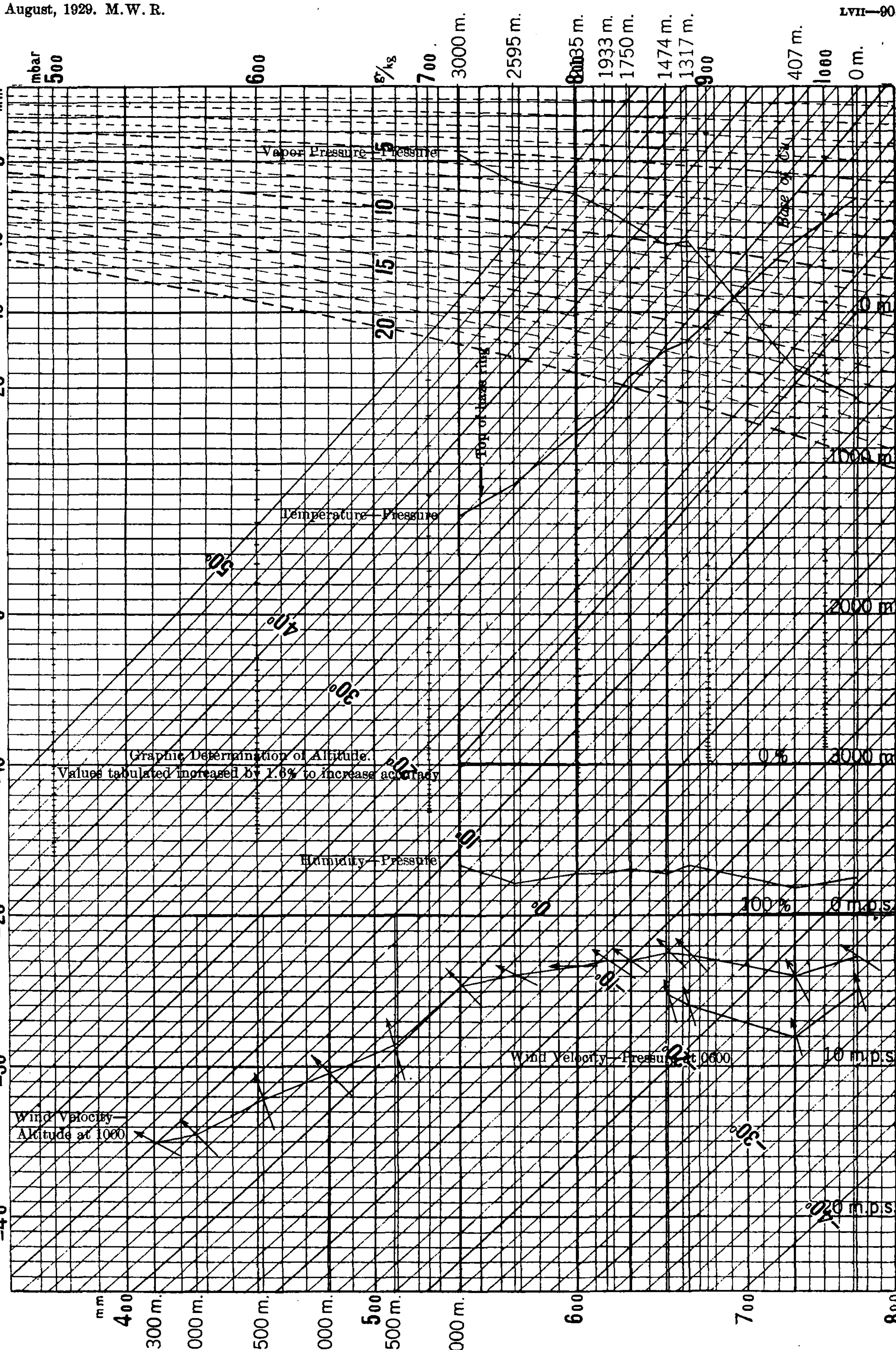

P. G. H. Fig. 2. Adiabatic Chart

there is a large energy area, as on the accompanying tephigram chart, thunderstorms almost invariably follow during the day.

At 8 a. m. on June 14, when observations were being made for the aerological record, it was noted that there were seven-tenths cumulus clouds with a prevailing direction from the south. It was noted, however, that some cumulus moved from the west and some from the southwest. These observations were made with a Weather Bureau type nephoscope. By 9:30 the development of the cumulus had continued until forms of cumulo-nimbus were appearing. There was a partially developed cumulonimbus to the south over the Gulf from which rain was falling. There was another to the west, about 5 miles off, from which rain was falling, and to the north, about 10 miles distant, was a third from which rain was falling. This was the setting as observed by the writer, who was on top of the observatory to watch the developing squalls in order to warn the squadrons of possible dangerous weather for flying.

By chance, attention was directed toward the north, where at 9:31 the waterspout formed. It formed about 2 miles to the north of the station and about a half mile offshore. It lasted six minutes—until 9:37. During that time it moved very slowly in a general southeast direction. This was determined by observations from the observatory and from planes in the vicinity.

The waterspout was observed from the aerological observatory to form in the clouds and descend to the water. The descent did not take more than 20 seconds. The descending column laid over flat under the cloud and then descended rapidly in an arched shape. As viewed from the south the column had a shape similar to that shown in the picture, except that the slope was to the right or east. In the picture the slope is toward the left or south, so that actually the column sloped toward the southeast, which was its general direction of movement.

When the waterspout first appeared, a landplane was ready to take off from the station field with a photographer. Its regular mission was delayed and the plane flew near the waterspout, where two exposures of it were made. Only the picture accompanying this report turned out well. From the pilot who flew the plane, Lieut. (Junior Grade) H. S. Duckworth, U. S. Navy, and the photographer who accompanied him, G. A. Carroll, private first class, U. S. Navy, the data of the next paragraph were obtained.

The altitude of the base of the cloud from which the waterspout descended was 1,100 feet by the plane's altimeter. The picture was taken looking toward the west when the plane's altitude was 500 feet. The base of the waterspout was estimated to be one-half to three-quarters of a mile off shore. The plane was approximately 1,500 feet from the waterspout when the picture was taken. The waterspout was between 20 and 30 feet in diameter. At the base, faintly discernible in the picture, was an outer whirl of cloud or spray concentric with the waterspout, about three times its diameter and extending upward 50 feet from the surface of the water.

In the background of the picture is what appears to be another waterspout forming. This was not observed by anyone and is thought to be rain falling or a defect in the negative.

Many people who were close to the waterspout, including those who were in the photographic plane, were questioned regarding the direction of rotation. This important evidence was not obtainable, as no one seems to have noted it. Neither was thunder or lightning observed in connection with the waterspout.

The waterspout disappeared more rapidly than it formed. It was seen to break near the surface of the water and rapidly draw up into the cloud above.

This report is prepared because it is thought that this is the first time data of the character presented here has been available in connection with the study of waterspouts. No conclusions will be attempted other than to suggest that the predominating feature in the formation of this waterspout was vertical convection. The pilot balloon ascent taken immediately after the formation of the waterspout shows a general southwest wind which varied from south to west-southwest. While the noted movements at 8 a. m. of cumulus clouds from the south, southwest, and west indicate a difference of direction of the upper air perhaps sufficient to initiate a whirl, the tephigram certainly shows a large supply of energy to produce an accelerated vertical convection.

TABLE 1.—*Work sheet used in transcribing the data from the airplane meteorograph record sheet, June 14, 1929, at Pensacola, Fla.*

	Wind		Temperature (correct base line 26.5° C.)					Potential temperature (reference to 750 mm.)		Pressure (correct base line 765 mm.)					Humidity (correct base line 77 per cent)				Vapor pressure	Dew point		
																				Tables 72 or 78, Smithsonian		
Significant points	Direction to 16 points	Velocity (m. p. s.)	Ordinate difference	Factor	Corrected ordinate difference	Correct temperature °C. (base line+corrected ordinate difference)	°C. absolute (corrected °C.+273)	°C.	°C. absolute (°C.+273)	Ordinate difference	Factor	Temperature correction	Corrected ordinate difference	Correct pressure (mm.) (base line+corrected ordinate difference)	Ordinate difference	Factor	Corrected ordinate difference	Correct humidity, per cent (base line+corrected ordinate difference)	Table 78, Smithsonian	°C.	°C.—Absolute (°C.+273)	Computed altitude (meters)
0	WSW.	4.9	+1.0	1	+1.0	27.5	300.5	25.0	298.0	+6.0	0.94	0	6	771	−2.0	0.8	−2.0	75	20.65	22.6	295.6	0
1	WSW.	8.0	−2.0	1	−2.0	24.5	297.5	27.0	300.0	−38	.94	0	36	729	+6.0	.8	+5.0	82	18.92	21.2	294.2	407
2	WSW.	6.1	−8.5	1	8.5	18.0	291.0	28.5	301.5	110	.94	0	103	662	−13.0	.8	−10.0	67	10.38	11.8	284.8	1,317
3	WSW.	5.3	−9.0	1	9.0	17.5	290.5	29.5	302.5	122	.94	0	115	650	−8.0	.8	−6.0	71	10.65	12.2	285.2	1,474
4			−11.0	1	11.0	15.5	288.5	31.0	304.0	147	.94	0	138	627	−10.0	.8	−8.0	69	9.13	9.9	282.9	1,750
5			−13.0	1	13.0	13.5	286.5	30.5	303.5	160	.94	0	150	615	−7.0	.8	−6.0	71	8.25	8.4	281.4	1,933
6			−14.5	1	14.5	12.0	285.0	31.0	304.0	177	.94	0	166	599	−7.0	.8	−6.0	71	7.48	6.9	279.9	2,135
7			−18.0	1	18.0	8.5	281.5	32.0	305.0	212	.94	0	199	566	+3.0	.8	+2.0	79	6.57	5.1	278.1	2,595
8			−20.0	1	20.0	6.5	279.5	34.5	307.5	240	.94	0	226	539	−13.0	.8	−10.0	67	4.87	0.8	273.8	3,000